BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 03093

SUBJECT: Flight Control: A Definition
Case 105-3

DATE: March 14, 1969

FROM: J. H. Fox

ABSTRACT

A control function, which in this memorandum is called "flight control," is being applied to virtually all spacecraft in the inventories of the Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), the Manned Spacecraft Center (MSC) and the Air Force Satellite Control Facility (AFSCF). Although the general nature of this function, as performed at these four controlling agencies, is somewhat the same, a common description of what it includes and where its bounds lie has never been advanced.

Operationally, this deficiency has not been significant. As budgets become constrainted however, a more precise understanding of the scope of this function will be essential if the many ctivities that comprise a total space program are to be assigned eir proper niche and exercises in semantics avoided.

The purpose of this memorandum is to illuminate this ıbject and to stimulate thought concerning it. "Flight control" presented as a function which encompasses only those subınctions essential to the conduct of the flight. The function defined, its domain is prescribed, current approaches to it e discussed and conclusions concerning its relationship with her, peripheral, space program activities are presented. We onclude that the function can be readily identified in terms of ı-line and off-line activities associated with the spacecraft roper and with the network through which the craft is controlled.

We conclude that, initially, a "black and white" approach should be taken and all non-essential activities, even hough related, should be set apart from the expensive flight ontrol function and given separate identity. Once so identiied, exceptions in mode of operation can be made and overlaps olerated so long as each is clearly recognized as an exception nd not allowed to grow into an ill-defined interface. We conlude that with this approach, significant economies can be ealized without jeopardy to mission success by the elimination f unnecessary effort, by ensuring that activities which do not support flight control are conducted outside the expensive flight control structure, by combining similar activities, by sharing and scheduling people and equipment where feasible and, most importantly, by allowing greater management visibility in this costly area.

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MEMORANDUM FOR FILE

INTRODUCTION

Almost from the first satellite launch, spacecraft have been "controlled" in the sense that they could be commanded to respond to instructions from the ground. This "control" aspect of space flight is often alluded to in publications and in verbal discussions. "Flight control," as practiced at the Manned Spacecraft Center (MSC), Houston, is well defined in the course material and publications of the Flight Control Division.* Nevertheless, when the total space community is canvassed, the topical area covered or implied by the term "flight control" remains ill-defined, and differing connotations are assigned it according to how and by whom used. Most often the specific term "flight control" is not used at all although a general functional area having somewhat similar characteristics is present in the operational environments of the Goddard Space Flight Center (GSFC), the Space Flight Operations Facility (SFOF) of the Jet Propulsion Laboratory (JPL), the Manned Spacecraft Center (MSC), the Air Force Satellite Control Facility (AFSCF), the aerospace industry and the scientific community.

In a work-a-day context, this vagueness has not been especially important since there has come about through evolution an adequate understanding of what is contained in that function which comprises the command and control of spacecraft. As budgets become constrained however, it appears that a more precise, if not universally accepted, understanding will be needed of where the bounds of this area lie. Such an understanding will be essential, especially to top management and planners, if time-consuming exercises in semantics are to be avoided and if valid judgements are to be made concerning where the many activities that make up a total space program are to be assigned and charged.

It is the purpose of this memorandum to further illuminate this subject, to stimulate thought concerning it, to suggest what constitutes "flight control" and, perhaps most importantly,

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*See, for example, "Introduction to Flight Control," SCD No. T.01, 3/1/68, Flight Control Division, MSC, Houston, Texas.

to suggest where the bounds of the flight control function should lie--that is, to suggest what flight control is not. Throughout, the discussion is non-specific; that is, without regard to a particular organization or to a particular program at any one geographic location.

FLIGHT CONTROL DEFINED

In this memorandum it is taken as fact that in any current or future space flight endeavor a control function will exist. While this point may appear subtle (or, perhaps, unnecessary) it is an important one since it means that the day of the completely unresponsive spacecraft, uncapable of being commanded, has virtually ended. It is also taken for granted that the bulk of the space community would agree, in principle at least, that this control function, which in this memorandum we will call "flight control"* could be defined something like: "that function which integrates the launched spacecraft and the ground system in a manner such that the success of the mission is maximized." This definition, paralleling somewhat the one published by the Flight Control Division (MSC), has been broadened to include unmanned as well as manned spacecraft and also to include the total ground system, from the operations console to the antenna. In this context, "flight control" is a function which amalgamates the efforts of other functions; it is not an organization.

The exercise of the flight control function is the dominant (but not necessarily the only) activity during the third of four major phases in the life cycle of any spacecraft, these being (Figure 1):

1. the fabrication phase which includes development and test;

2. the launch phase which includes mating to booster and intermediate stages and total on-pad system checkout;

3. the flight phase, during which control of the spacecraft is exercised and data are obtained and;

4. the recovery on earth phase or alternatively, the demise (through impact or electronic failure) phase.

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*Other descriptive terms could be, and often are, assigned this function. It is only important, for the purpose of this memorandum, to clearly keep in mind that a functional area is being discussed. The name given it is of secondary importance. "Flight Control" was chosen as the one most nearly descriptive of all terms available and as the one likely to be familiar to most readers.

THE DOMAIN OF FLIGHT CONTROL

The domain of flight control extends from the point where a decision is considered/reached, up to and including the execution of that decision by the spacecraft or the network.* Flight control coordinates and controls the actions of all the people and all the hardware and software in the chain. It is personified by a senior "flight controller" who is the final authority on and who has final responsibility for all matters involving adherence to the flight plan. His decisions are subject to override by higher authority when mission success is an issue or, in a manned vehicle, by the astronaut commander when safety of flight is involved. Since the flight control on-line** responsibility begins at either lift-off or at booster burn-out and ends at splash down or demise it differs from what is often referred to as "mission control" which concerns itself with <u>all</u> aspects of the mission. Flight control closely integrates the actions of several subfunctions--tracking station control, communications, and data handling are three. When operating, all these essential subfunctions come under the aegis of flight control. How closely they should be coupled, organizationally, is partly a policy matter and is not considered further here.

Timewise, the exercise of the flight control function could begin (with preparations and rehearsals) as early as the fabrication phase depending on the program. It always includes the planning, the pre-flight preparation, the training of personnel and the system integration and checkout preparatory to actual flight. It almost always continues beyond the life of the spacecraft in the form of critiques, post-mortems and corrective actions. Activities reach a crescendo during the inflight period with the dominant activity being conducted in real time or near real time.

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*In this paper "network" includes all of the supporting resources not necessarily "used" or controlled solely by any one program; i.e., it is the end-to-end aggregate of equipment and people beginning with the antenna at the tracking site which transmits or receives the spacecraft signal and ending at the console or other data presentation/display device at the ultimate control point, usually, a control room. In general, the "network" is not concerned with the detailed activity, problems or command actions associated with any one spacecraft.

**Appendix A defines "on-line", "off-line", "real time", and "near real time", as used in this memorandum.

APPROACHES TO FLIGHT CONTROL

Within the National Aeronautics and Space Administration three approaches to the exercise of the flight control function have developed. At the risk of oversimplification these are:

The shared resource approach typified by JPL where the time dynamics of deep space operations have encouraged the sharing of a common system by all programs such as, for example, Pioneer and Mariner. Shared are the major elements of the Deep Space Network (DSN)--the tracking stations of the Deep Space Instrumentation Facility (DSIF), the Ground Communications Facility (GCF) and the Space Flight Operations Facility (SFOF) at Pasadena.

The semi-shared resource approach taken by GSFC where some equipment--primarily computers, rooms, and consoles--is dedicated to each of the more complex programs such as OAO, OGO and TIROS* while other less complex programs such as Biosat, RAE, and AIMP* share control rooms, consoles and computers. All GSFC programs share general purpose computers for trajectory determinations and the use of the STADAN.*

The dedicated system approach taken thus far by MSC wherein all elements of the system--the Mission Operations Control Room (MOCR), the Real Time Computer Complex (RTCC), the Communications, Command and Telemetry System (CCATS) and the Manned Space Flight Network (MSFN)--have been designed for, modified for, and dedicated to one program at a time. (Although this has been the pattern thus far, interests of accuracy require us to note that the manned system could, at any time, be configured to handle two different manned programs simultaneously if required.)

These three approaches, not unnaturally, reflect the category of the mission whether deep space, earth orbital, unmanned, or manned. A fourth approach, which combines somewhat the MSC and GSFC approaches has been developed by the Air Force Satellite Control Facility (AFSCF). Here, all programs share the tracking stations, the communications network and the data processing facilities. Also, mission control rooms, data display

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*OAO - Orbiting Astronomical Observatory
OGO - Orbiting Geophysical Observatory
TIROS - Television Infrared Observation Satellite (Meteorological satellite)
RAE - Radio Astronomy Explorer
AIMP - Anchored Interplanetary Monitoring Platform
STADAN - Space Tracking and Data Acquisition Network

devices and consoles are modular and are largely interchangeable between programs. The Manned Orbiting Laboratory (MOL) however, will represent a partial departure from this philosophy since, initially, it will use certain dedicated computer equipment.*

While category of mission--deep space, earth orbital, unmanned, manned--has predominated in influencing the particular approach taken towards flight control, a second factor, cost of operation, has also been a determinant. There is evidence which supports the conclusion that cost, or more precisely an insufficiency of funds, can be the overriding consideration causing the ground support network to evolve in a manner such that programs begin to share common facilities, techniques, personnel and equipment. Conversely, evidence indicates that an increase of funds tends to encourage programs to develop and deploy program-peculiar equipment which may have little or no utility to other programs. Additionally when flight control functions are being exercised on two or more spacecraft simultaneously, the concept of multiple operations is introduced. When resources are limited, time-sharing of people and equipment usually takes place so that the flight control function may be exercised on any one spacecraft on a temporal basis--that is, with resources assigned during a specific block of time only. When not specifically assigned, resources are returned to the common inventory and become available for rescheduling. While these principles apply mainly to the ground-support network, it is somewhat axiomatic that the configuration of this network, in turn, strongly influences the nature of the associated flight control function and indeed, on occasion, the configuration of the spacecraft itself.

TIME DYNAMICS OF FLIGHT CONTROL

The flight control function can be broken into two distinct, but closely related parts: one which is concerned with spacecraft oriented activities (or program oriented activity if there is more than one spacecraft in the program) and another

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*Additional information on the Advanced Data System (ADS) now being installed in the AFSCF is contained in Memorandum for File, "USAF Satellite Test Center Advanced Data Subsystem (ADS)," dated, February 18, 1969.

which is concerned primarily with network oriented activities. These activities and their time-dynamic modes can be grouped in a two by two matrix:

Flight Control Functions \ Time Dynamics	On-Line	Off-Line
Spacecraft (Program) oriented		
Network oriented		

The principal feature which distinguishes on-line activities from off-line is time. When conducted on-line, actions are closely geared to schedules and the time-dynamics of a mission. Flexibility in when things need be done is constrained. Off-line activities on the other hand can generally be "fit-in" to the schedule as time and resource availability permit. Off-line flight control activities are restricted to those which directly contribute to the success of the flight.

ON-LINE SPACECRAFT ORIENTED ACTIVITIES

All on-line spacecraft oriented activities can be fit into three categories:

1. Analyses, which are of two types:

    (a) Trajectory analyses and ephemeris generations.

    (b) Spacecraft analyses (orientations, maneuvers about the C.G., status and trends of both craft and science subsystems).

2. Control (decision making, flight plan assurance or alteration).

3. Command (command status, command generation).

These are areas of prime interest. Basically, the functions that are performed in these areas are analyses, decisions, and executions (of decisions).

Each of the three prime categories listed above represents a subset of the flight control function and each in turn is served by people skilled in broad, but unique and identifiable, disciplines. Having said this (and it is important to make the distinction) too much should not be made of it since the people who perform these on-line spacecraft oriented activities function closely as a team with considerable interaction occurring within the group. Finally, it needs saying that while all the subfunctions of the spacecraft oriented aspects of flight control can be fit into these categories, the amount of emphasis each receives is a function of the spacecraft (or program) and its mission. An example is the area of ephemeris generation and trajectory analysis. Here the emphasis will range from relatively minor, for a solar orbiting, non-maneuverable craft,* to major for a low earth orbit, high drag, maneuverable craft.

<u>ON-LINE NETWORK (GROUND) ORIENTED ACTIVITIES</u>

On-line network oriented activities include all on-line functions performed <u>not</u> necessarily in support of any one spacecraft or program. Typically, these include:

1. Network Control.
2. Communications.
3. Readiness Checks and Certifications.
4. Fault Isolation.
5. Status Reporting.
6. Resource Allocation: Short Range Scheduling.
7. Conflict Identification and Resolution.
8. Data Management (acquisition, processing and routing).
9. Data Display and Presentation.

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*Or even none at all for the Apollo Lunar Surface Experiments Package (ALSEP).

10. Liaison with other Non-Organic, Agencies.

11. Weather Support.

12. Emergency Repair and Maintenance.

The list is illustrative. It rather obviously assumes that more than one spacecraft is being controlled by the network. In a complete listing, all the functions necessary to insure the proper and timely functions of the network would be included. The functions listed are generally self-explanatory; however, two might require further clarification: (1) conflict identification and resolution is required since there will be occasions when two or more spacecraft desire to use the same resource at the same time (e.g., an antenna) or when the sole use of a resource by one could adversely affect the performance of another (e.g., RFI); (2) emergency repair and maintenance includes only that which is required to immediately place back in the inventory a failed item which has been scheduled and which is critical to a particular phase of a spacecraft flight. All other repair and maintenance would be an "off-line" function.

OFF-LINE ACTIVITIES

As defined, these are all other activities which need be pursued in order to accomplish the flight control function but which need not be rigorously scheduled; that is, while it is necessary that they be done, when they are done is not (within reasonable limits) a critical consideration. Typical off-line spacecraft oriented activities include the development and publication of flight rules, flight plans, procedures, software generation, spacecraft status and trend analyses of use during the flight period but not necessary for on-line control, most preflight preparations, reviews and readiness certifications and post-flight evaluations, critiques, and reports. Typical off-line network oriented activities include the development and publication of network rules, procedures and documentation, generation of general purpose network software, maintenance, equipment modification, configuration control, routine outage reporting, certain data processing and the issuance of resource forecasts and schedules.

While it is important to separate them for ease of identification and management visibility, the on-line and off-line activities, being distinguishable primarily by their time dynamics, are complimentary and should be viewed as such by management. The flight control operator will so view them in any event.

FLIGHT CONTROL INTERRELATIONSHIPS

When two or more spacecraft begin to share resources, or an entire network, the functional interrelationships become complex. In a situation where, perhaps, as many as ten programs, with say fifty spacecraft of varying complexity all share one common network the result can rapidly become unmanageable unless the functional relationships are carefully prescribed and adhered to. Because the subject is broad no one diagram can adequately portray these relationships; however, Figure 2 is an overview of the interrelationships of the subset of activities which comprise the total flight control function. A multi-spacecraft, single network, environment was chosen in an attempt to portray as complex a picture as possible. The two major activities--spacecraft oriented and network oriented--lend themselves to a natural separation for understanding. The backgrounds and training of the people comprising the two groups are different. Network oriented personnel are well versed in the ground (network) system--characteristics of the sites, communications lines, data transmission and processing, and the ability of the network to respond to given situations. Station and equipment turnaround times, backup capabilities, even skill level of site personnel often are critical factors in determining how or when a particular contact is to be made to a spacecraft and network personnel must be knowledgeable in these areas. Spacecraft oriented personnel, on the other hand, may have little first hand knowledge of network capabilities but are expert on their particular craft. They are well versed, not only in its design configuration and response characteristics, but also on the idiosyncrasies of each particular flight article whether the idiosyncrasy developed during the flight or was identified before flight from a detailed knowledge of the problems encountered in the fabrication of the craft.

WHAT FLIGHT CONTROL IS NOT

There are a host of program, mission, or flight related, off-line activities which, while necessary for the success of the program, are not essential to the success of the flight control function. For example, in a number of programs data are recorded passively by the Principal Investigators (P.I.'s) or other operational users. A case in point is the operational TIROS Satellites (TOSS) from which the Environmental Sciences Service Administration (ESSA) obtains meteorological data directly. Unless the facilities of the flight control network itself are used, to either receive the data or to issue commands to the spacecraft, this type of activity does not impact the flight control function and, thus, is not a part of it. Another example is data processing and analyses for post-flight engineering or scientific studies. On occasion, particularly if the flight is of long duration, such studies do indeed improve the quality of the mission and may even help insure its success; thus a close interface relationship is maintained. Engineering and scientific analyses for understanding and art state advancement, are important pursuits--indeed, it can be comfortably argued that they are the principal reasons for the programs' existence in the first place. It is most important to efficient management, however, that all these related, but non-flight control, activities retain a distinct and separate identity. Failure to clearly identify their separate status tends to reduce management visibility in a most critical and potentially costly area. It is here that high costs can be incurred inadvertently in order to supply unneeded real time, or near real time information when slower means of delivery, and processing, outside the expensive flight control system, can be used. The point is worth repeating that, when viewed in its purest sense, the flight control function encompasses only those activities which contribute directly to inflight success and no other. Clarity of this concept is essential if cost effectiveness is a goal, if duplication and unnecessary efforts are to be reduced, if "hobby-shops" are to be controlled, and if a clear understanding of how the system works is to be imparted to all working-level personnel.

SUMMARY AND CONCLUSIONS

The successful conduct of a space flight program is the end result of the efforts of many people. With respect to activities relating to the spacecraft itself these people and the tools they use can be assigned to four major phases for ease of identification: these are fabrication, launch, flight, and recovery. The types of individuals engaged in each of these phases, and the equipment they use, is sufficiently unique to warrant looking on them as belonging to four separate disciplinary communities.

The control of spacecraft in flight has resulted in the evolution over the past ten years of a disciplinary function, here called "flight control", which while extensively practiced has thus far been ill-defined except in local applications. From a purely operational point of view, this lack has not been harmful since the people involved have been skilled, have known what they were doing and why, and the results, nationally have been eminently successful. It is not at all certain, however, that the total national effort has been cost effective. If one wishes to critically examine the national space program in an attempt to reduce overall cost while, at the same time, running no risk of impairing success, a better understanding of what constitutes each unique and identifiable phase of a program is necessary. To do this, interfaces must be cleanly (even ruthlessly) defined. It is recognized that often, particularly in day-to-day activities, overlaps occur. Indeed, informal crossing of interfaces is essential to a smooth working system and must be encouraged. Nevertheless, we conclude that adequate management visibility requires, as a first cut, a "black and white" approach to the problem if understanding is to be achieved and cost effectiveness is an objective.

In this memorandum, flight control is defined as the dominant function exercised during the third of the four major phases in the life cycle of a spacecraft. We conclude that the bounds of flight control lend themselves to a natural, disciplinary break-out and can be precisely determined. We conclude that "flight control" includes only those subfunctions necessary for the conduct of the flight--for the "care and feeding" of the spacecraft and its payload. Included are subfunctions that are conducted both on-line and off-line and which relate to both the spacecraft and the network through which the craft are controlled.

All spacecraft flight control activities can be conveniently fit into three categories--analysis, control and command. These represent the fundamental processes of analysis (of the basic craft, of its payload, and of its position and maneuvers), decisions and execution of decisions. All network flight control activities, which by definition are non-spacecraft specific, can be similarly fit into a finite number of categories (scheduling, status reporting, conflict identification, liaison, etc.).

Flight control, particularly on-line and in real time, is expensive and resource consuming. Thus, peripheral activities deriving support or benefit from the flight control activity, but not <u>required</u> in support of flight control, must be clearly identified and set apart. Essentiality to the flight control function must be the criterion; mere desirability is not sufficient. Once so identified, exceptions in mode of operation can be made and overlaps tolerated. Often this is desirable in the "real world" for cost effectiveness and convenience. But the point is made that each exception should be clearly recognized as such and not allowed to grow into an ill-defined interface. We conclude that, once having made this identification, significant economies can be realized without jeopardy to mission success by the elimination of unnecessary effort, by ensuring that non-flight supporting activities are conducted outside the costly flight control structure, by combining activities and sharing people and equipment where feasible and by allowing greater management visibility in this area.

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Attachments
Appendix A
Figures 1 and 2

APPENDIX A

On-line, off-line, real time and near real time are terms which have been assigned different meanings at different times depending on the background of the user and on the subject and context to which they have been applied. A broader application is usually intended when they are used in flight operations discussions than in, say, computer operations. Here they are generally used as follows:

On-line Functions - Those functions performed in close proximity, timewise, to a contact between a control point, a tracking station and, usually, a spacecraft. On occasion, one of these elements may be missing. For example, functions could be performed "on-line" during simulations or rehearsals where an actual spacecraft was not involved. Physical presence at a "place of duty" is required of participants. Equipment (hardware, software, communications) is either being used or capable of being used when required; it is not available for any other purpose. Scheduling of network resources (usually end-to-end from the operator/console at the flight control point to the antennas) is in effect. On-line is a broader category than and encompasses real time and near real time.

Off-line Functions - Any that are not on-line are off-line. Time is not a crucial factor. Constant physical presence of the participant is not required. Considerable flexibility in scheduling is allowed. No intimate relationship to the flight dynamics of the spacecraft, real or simulated, exists.

Real Time Functions - Those functions performed in a time interval such that the observed results can be used to guide or modify the process in effect at that time. Specifically, the sending of commands or the receiving of data from a spacecraft in a time interval measured only by the passage of an electronic signal from the point of initiation of the signal (switch closure) to final acknowledgement of receipt of the signal either within the spacecraft or at a display device on Earth. Generally the interval is a function only of the time required for switch activations, computer operations and signal travels but also is extended to include the time required for the operator to note the result (i.e., that the desired action has taken place). An example is the switching of telemetry modes in a spacecraft upon ground command. Real time switching would include the time required from the initiation of the sending of the command, to the observation (at either the tracking station or at the flight control point) that the spacecraft has accepted the command for later action or has indeed responded to it and new telemetry parameters are being observed.

Near-Real Time Functions - Those functions performed in a time interval such that a series of actions are taken with minimum delay. Virtual instantaneous response by the operator is necessary. Equipment-wise the action is usually in real time but operator-wise a decision process is usually involved. However, lengthy delay is not permitted. Generally there is not time for extended conferences to determine courses of action. The operator makes his decision based on prior analyses and on previously agreed upon "if this, then that" type logic.

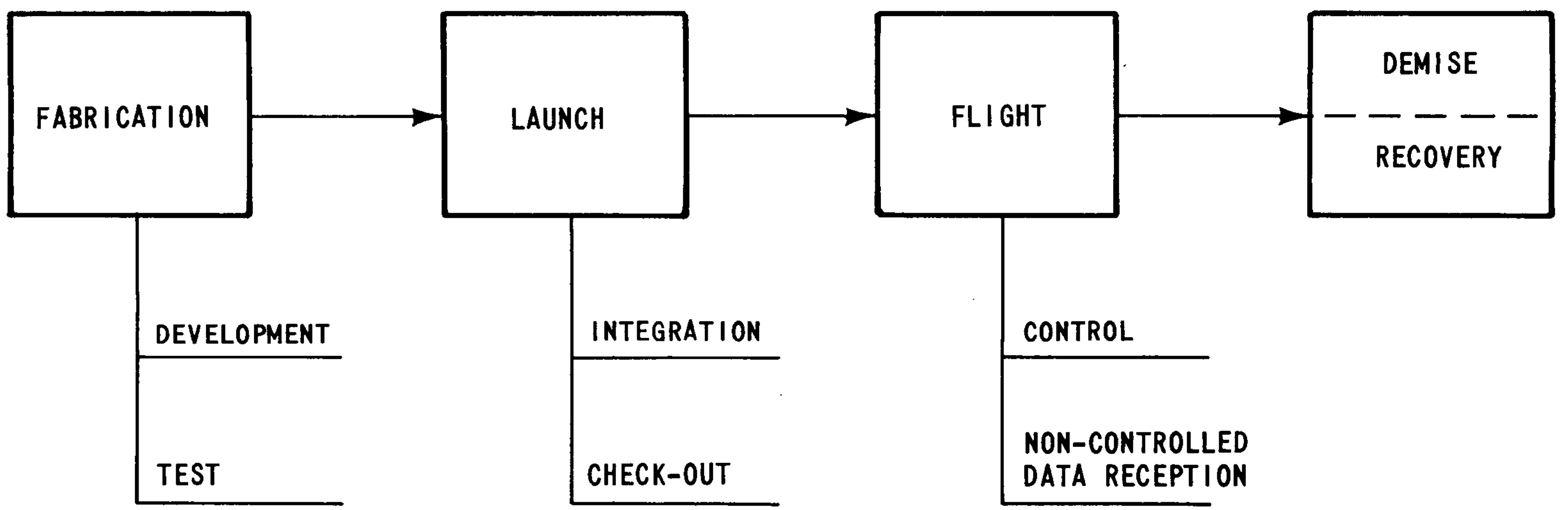

FIGURE 1 - MAJOR PHASES IN THE LIFE-CYCLE OF A SPACECRAFT

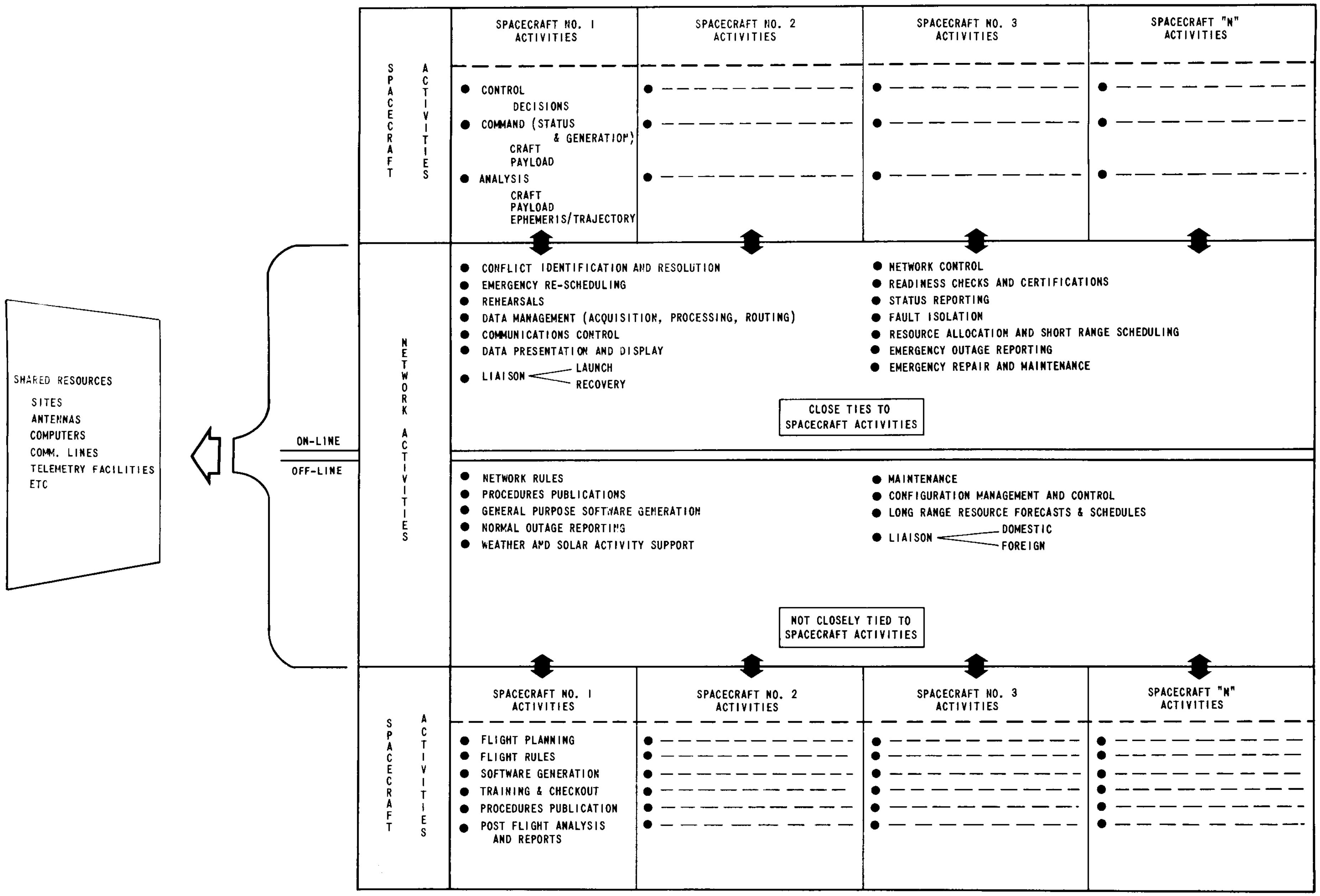

FIGURE 2 - THE INTERRELATIONSHIP OF FLIGHT CONTROL FUNCTIONS IN A MULTI-SPACECRAFT ENVIRONMENT

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